

Source of Acquisition  
NASA Johnson Space Center

*Final*

## **AIAA 2001-2042**

# **Development Of An 80'-Diameter Ribbon Drogue Parachute For The NASA X-38 Vehicle**

Vance L. Behr  
Sandia National Laboratories  
Albuquerque, NM

Dean F. Wolf  
Consultant  
Albuquerque, NM

Bruce A. Rutledge and F David Hillebrandt  
United Space Alliance  
Kennedy Space Center, FL

**16<sup>th</sup> Aerodynamic Decelerator Systems  
Technology Conference & Seminar  
21-24 May 2001  
Boston, Massachusetts**



AIAA 2001-2042

## DEVELOPMENT OF AN 80'-DIAMETER RIBBON DROGUE PARACHUTE FOR THE NASA X-38 VEHICLE

Vance L. Behr\*  
Sandia National Laboratories†  
Albuquerque, NM

Dean F. Wolf‡  
Consultant  
Albuquerque, NM

Bruce A. Rutledge and F David Hillebrandt  
United Space Alliance  
Kennedy Space Center, FL

### Abstract

The NASA X-38 program required a larger, more robust drogue parachute. A multi-organizational team from NASA, Sandia National Laboratories, United Space Alliance, and Pioneer Aerospace Corporation has developed and tested a new 80-ft.-dia., quarter-spherical, ribbon drogue parachute. The design requirements, design specifics, margin analyses, and results of testing are all discussed herein. Some of the weight advantages of switching from Kevlar to Zylon for radial, line and riser materials are presented.

### Introduction

The NASA X-38 program at the National Aeronautics and Space Administration's, Lyndon B. Johnson Space Center (NASA-JSC) is developing technologies to be applied to the Crew Return Vehicle (CRV)<sup>1</sup> for the International Space Station (ISS). Specifically the CRV is a lifting body shape that will reenter the earth's atmosphere, ultimately being soft-landed with a parachute recovery system. The current vehicle requirements call for both a primary and backup parachute system. This drogue will be used in the primary parachute system. The main parachute system consists principally of a supersonic programmer, a retarding drogue, and a large parafoil parachute.

The parafoil system is an outgrowth of NASA's Advance Recovery Systems (ARS)<sup>2</sup> and the Army's Guided Parafoil Airborne Delivery (GPAD)<sup>3</sup> programs. The original weight of the X38 vehicle allowed for one of the original ARS/GPAD 60-ft.-dia. drogue parachutes to be employed. As the testing program proceeded, the drogue parachute deployment velocities and the estimate of the CRV weight increased ultimately requiring a new drogue parachute design. The primary purpose of the drogue is to establish a dynamic pressure at the time of main parafoil deployment that will allow manageable opening dynamics and loads for the large parafoil. In the spring of 1999, at NASA-JSC's request, staff from both Sandia National Laboratories (SNL) and the Parachute Refurbishment Facility (PRF) at the NASA Kennedy Space Center (KSC) operated by the United Space Alliance (USA) undertook a joint design effort to meet the X-38 requirements.

The design and development effort has utilized many traditional design aspects of drogue parachutes but has also employed some more modern design aspects and materials. The development process has been fairly fast-paced, involving various stages of testing that are described herein. The location of the drogue parachute for the primary parachute system is at the extreme tail end of the X-38 vehicles. The current weight and balance of the X-38 vehicle dictate that the primary

\* Principal Member of Technical Staff, Associate Fellow of AIAA

† Sandia National multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

‡ Associate Fellow of AIAA

This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.



drogue parachute be as light as possible, every pound saved resulting in a net savings of two pounds due to offsets in balance weights. This precious weight consideration has driven the program to use an emerging material in the parachute industry known as Zylon. Significant material characterization tests are being performed to establish confidence in using this new material. Unfortunately space limitations and insufficient data to date preclude meaningful discussion and definitive statements in this paper.

### System Design

The design of the drogue parachute system is divided into that of the Canopy, Reefing System, Suspension Lines, Riser and Deployment Bag. Each of these are discussed in the following sections. As with any program, the design requirements have changed as the program has progressed. However, the original design was based upon the circa-1999 design requirements<sup>4</sup> as listed in Table 1.

#### Canopy

At the outset it was realized that the required dynamic pressure at deployment exceeded the recommended upper limit for ring-slot parachutes. This was reinforced by results from early tests at NASA's Dryden Research Facility of the original GPADs based 60-ft.-dia. ring-slot drogue parachute. The higher dynamic pressure conditions dictated the use of a ribbon parachute more typical of this flight regime.

Historically, parachutes canopy shapes were flat circular. Later the more efficient conical shape was introduced, either in the form of a singularly conical shape or in bi-, tri-, or poly-conical shapes. Given computing resources in today's environment, it is quite easy to tailor a canopy to have any shape one desires. In fact, a quarter-spherical design has been shown to be very efficient in terms of drag area per nominal area of the canopy. This can be seen in the increases in the nominal coefficients of drag realized for the different kinds of canopy shapes as shown in Table 2. Past and present programs that have employed the quarter-spherical shape include: Gemini, Apollo, the F111 crew escape module, the Boeing EELV recovery system, the Shuttle Rocket Booster Light Weight Main, and the Kistler (K-1) Mains.

Also, in recent programs such as the Light Weight Main for the Space Shuttle and the recovery parachute for the Semi-Deployable Wing (SDW), the quarter-spherical shape has been shown to be very damage tolerant due to the efficient distribution of stresses in the canopy. This

Table 1 Circa 1999 System Requirements

Payload Weight	25,400 lbs
Allowable Pack Volume	17,000 in <sup>3</sup> (9.8 ft <sup>3</sup> )
Target Parachute Weight	330 lbs
Max. Parachute Weight	366 lbs
Max. allowable deceleration	± 4G's (any direction)

#### Conditions at deployment

	$q$	Mach	Altitude
-Nominal	260 ± 35 psf	<0.6-0.7	23 ± 0.5Kft
-Off-Nom.	300 psf	≤ 2.0	60-80Kft

#### Temperature

-Survive	300 °F
-Reentry	<80 °F
-Operate	-65 °F to 115 °F

#### Pressure

-15.23 psia to 10<sup>-10</sup> torr

#### Materials

- Space-rated or ratable
- Use of metal links minimized
- Hermetically sealed reefing line cutters

#### Withstand fungus environment per MF004-014 ¶3.1.1.c

-Temperature	> 68 °F
-Relative Humidity	> 75%
-Materials non-nutrient to fungi	

#### Design Factors

- Safety Factors
  - 1.6 for testable components (2.0 Desired)
  - 2.0 for non-testable and critical (2.5 Desired)
  - 1.7 for supersonic (2.0 Desired)
- Safety Margins > 0.5

#### Storage Life - 10 years

- Cutters refurbished after 5 years

#### Redundant reefing or fault tolerant to any failed stage of reefing

Table 2. Typical Drag Coefficients for Different Shapes of Canopies

Type	Cd <sub>p</sub>
Flat	0.45 - 0.50
20° Conical	0.5 - 0.55
Quarter Spherical	0.6 - 0.65



manifests itself by rendering a large tear in a canopy gore almost indiscernible as opposed to other canopy shapes which deform greatly in the region of the tear.

The drogue canopy is nominally of traditional continuous ribbon construction. One exception is that a vent "hoop" is utilized instead of the more traditional vent lines. In this application, every other radial is looped over one of two vent hoops, the second vent hoop capturing the remaining radials. (See Figure 1.) This construction allows for redundancy in the vent structure and eliminates the vent-lines that can become very troublesome on parachutes with large numbers of gores. This construction technique is made possible with very stiff and high tenacity materials such as Kevlar which tightly control the vent shape without adding inordinate amounts of bulk to the vent region. In this parachute, the vent hoops are constructed out of multiple turns of braided Kevlar to get the strength necessary to establish positive margins with the high design factors required by the X-38 program for such critical components.

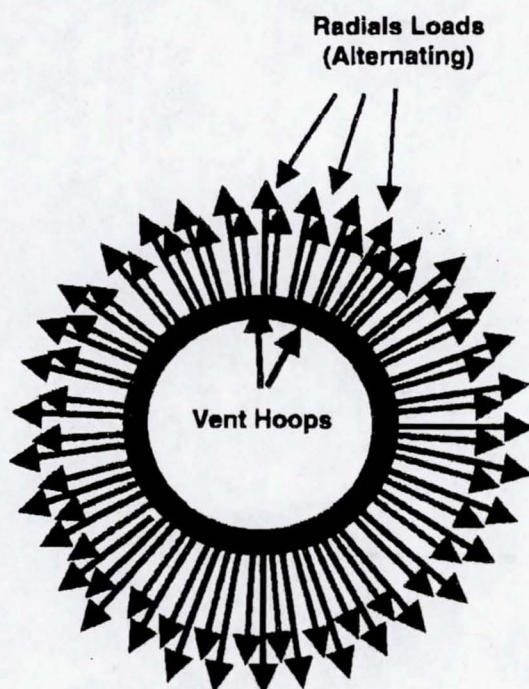


Figure 1.

#### Schematic of Vent Hoop Construction and Loading

The canopy is constructed of predominantly Kevlar and Nylon. The horizontal structure is nearly all Nylon, the exception being the vent-hoop, which is Kevlar. The radial construction is Kevlar for the main radials and Nylon for the mini-radials that control the gap between ribbons throughout the gores. Stronger horizontal elements replace ribbons periodically and serve as

rip-stops in a damaged scenario. The canopy consists of 203 horizontal elements and 80 gores. The specific canopy materials are shown in Table 3 & 4.

Table 3  
Horizontal Canopy Materials

Horizontal No.	Material	Purpose
2-55	"200#" Mil-T-5608 Class B Type 5	Ribbons
57-80, 82-104, 106-127, & 129-148	"380#" Bally Ribbon Mills P-6265	Ribbons
150-160, 162-173, 175-187, 189-202	"700#" Bally Ribbon Mills P-2565	Ribbons
56, 81, 105, 128, 149, 161, 174, & 188	"3000#" Mil-T-5608 Class E, Type 5	Rip-Stops
1	"	Skirt Band
203	"	Vent-Band
-	6500# Mil-C-87129 Type XII (4 turns per hoop)	Vent Hoops

Table 4  
Radial Canopy Materials

Member	Material
Outer Radial	9/16", 2750 lb., Kevlar Tape (Bally-Ribbon P-1813)
Inner Radial	5/8", 850 lb, Kevlar Tape (Bally Ribbon P-6435-5/8")
Mini-Radials	3/8", 120 lb, Nylon Tape (Bally P7282-5/16")

Due to its size, the canopy was constructed in segments. One segment was the "crown" of the parachute, that being the top portion of the canopy consisting of horizontal elements 149-203. The lower portion of the canopy was fabricated first as five identical "wall" segments consisting of 15 complete and 2 half gores each. These wall segments were then joined to each other (mid-gore) by sewing each individual horizontal



element to its corresponding element on the neighboring segment. The crown was then sewn to the lower portion by splicing each radial to the corresponding radial in the lower segment. This method allows for parallel operations to be performed leading to a more efficient and timely manufacturing process. It also reduces the requirements for long marking and assembly areas and reduces the amount of waste of horizontal material. It does of course require very efficient splices wherever they are employed.

### **Reefing System**

The reefing system for the drogue is relatively complex utilizing four reefed stages in addition to the final full-open stage. This is a result of the following requirements:

- Low peak loading (no more than 3 gs)
- High initial (295 psf) and low terminal (<10 psf) dynamic pressure
- Tolerance to a failed or premature reefed stage

The rings for each stage are tied to loops on the radials. The reefing rings are 7/8" O.D. by 5/8" I.D. and capable of withstanding at least 1000 lbs of radial load.

The reefing lines are fabricated from 10,000 lb braided Kevlar. They are marked with each radial location (equally spaced) before installation. After installation they are lightly tacked at each reefing ring with the exception of the 5 radials nearest the reefing line cutter (for that reefing line). This helps ensure an initial uniform inflation of each of the reefed stages while not interfering with the running of the reefing line through the rings after it is cut. The reefing lines are wrapped in Teflon tape in the region which is to be cut by the reefing line cutter. The reefing lines are sized to produce 6, 12, 25, and 50% of the full open drag area in each of the four reefed stages respectively.

### **Suspension Lines**

The suspension lines were sized to be 1.2 times the nominal diameter of the canopy (96 ft long). This has proven to allow for minimal reduction in drag for a quarter-spherical canopy without excessively long suspension lines. Originally the 80 suspension lines were made from 9/16" Kevlar Tape, the same material as outer radial. Later in the program braided Zylon lines were substituted as a weight savings measure. At the lower end they were grouped into 10 groups of eight and each group sewn to one leg of the ten-legged riser. At the top end, they were spliced to the radials in an overlapping joint utilizing the suspension line, and excess length of the inner and outer radial material.

### **Riser**

The drogue parachute must attach to the X38 vehicle via four heavy-duty slings. The drogue parachute must also be positioned far enough behind the payload to escape the worst of the wake effects of the payload. For test purposes, it is best if the transition between slings and the drogue parachute is separable. This allows the drogue to be packed in a traditional fashion, the slings be attached to the vehicle, and then the drogue be mated to the slings and installed in the vehicle. In this application, initially a 10 legged riser was of sufficient length to position the drogue at the intended location behind the vehicle. This riser was fabricated out of Mil-W-87130, Type X, Class 13, 20,000 lb Kevlar webbing. The ten legs were doubled at the lower end to pass over 5 pins in a fixture that adapted the drogue riser to the four main slings. This fixture was known from prior tests as the "Quad-Plate".

NASA had a desire to be able to handle a single fault anywhere in the system whenever possible. To cover the unlikely event that one of the riser legs may fail, "cross-over" straps were installed between adjacent riser legs to backup each individual leg against failure, albeit at reduced margins and/or design factors. A view of the riser in the cross-over strap region is shown in Figure 2.

### **Deployment Bag**

The deployment bag is constructed in the traditional fashion of a canopy compartment and a line compartment with compartment closure flaps and ties on each. The materials used are Spectra broad-goods for the bag walls and closure flaps with Kevlar reinforcing structure on the outside. This minimizes any contact of the Nylon materials in the canopy with Kevlar used in the bag construction. Instead the primary interface is between the canopy (Nylon and Kevlar) and the Spectra walls. Spectra being of very low friction coefficient minimizes any burn damage during the high-speed deployment process.

### **Weight Estimates**

The weight estimate for the drogue parachute system is shown in Table 5 component by component. Upon completion the parachute system weighed 324 lbs. This total can be compared to the desired and maximum weight of 330 and 366 lbs respectively. Efforts to seek additional weight gains in the system have led to the use of Zylon for the suspension lines and riser. These steps were taken incrementally and the drogue system with Zylon suspension lines (Kevlar riser and radials) weighs 286 lbs.





Figure 2.  
Riser Design with Cross-Over Straps

Table 5  
Estimate of Drogue Weight (lbs)

Component	Kevlar	Zylon
Canopy	178	161
Suspension Lines	68	35
Riser	31	25
Bag (w/Hardcover)		22
"Quad" Plate		26
Total	325	269

### Stress Analyses/Margin Calculations

To perform the stress analysis and margin calculations, nominal reefing and corresponding loading conditions had to be established. Then the parachute was analyzed with the CANO code. The stress was then compared to the nominal strength and plotted in non-dimensional form

### Loading Predictions

The original requirement was that no more than 3 g's could be put upon the crew. Backing off of that requirement a bit, a maximum design load of 63,000 lbs was established for the parachute by using a 2.5 g loading on a 25,000 lb vehicle. This maximum design load was then used to look at the number of stages of reefing required and what stress state would exist in each of the members of the parachute. Conventional inflation factors were used for each stage of reefing to obtain the following reefing and loading history. In doing so an estimate of the maximum expected load for each of the reefed stages of the parachute was calculated and are shown in Table 6.

Table 6.  
Estimate of Peak Load per Reefed Stage

Stage	Drag Area (ft <sup>2</sup> )	Reefing Ratio	Disreef Time (sec)	Peak Load (lbf)
1	180	6%	10	55659
2	364	12%	16	32963
3	735	25%	24	38996
4	1485	50%	27	38093
Full Open	3000	100%	-	32231

### Horizontals

The horizontals refer to the vent hoop, vent band, ribbons, rip-stops, and skirt band. The vent hoop can be analyzed by applying the load in the radial on a polygon with the number of sides equal to half the number of radials (due to the double vent-hoop capturing every other radial) and looking at the resulting tension in the vent hoop as shown in Equation 1. For the design load of 63,000 lbs, the radial load is predicted to be 512 lbs yielding an estimate of 3260 lbs in each vent hoop. The vent hoops were constructed out of four turns of 6500 lb braided Kevlar. With a design factor of 3.6, this yields a large margin of safety of 0.87 for this element.

$$Tension_{vent\ hoop} = \frac{(N_{Gores}/2) \times F_{radial}}{2\pi} \quad (1)$$

The loads in the ribbons, rip-stops and skirt band were all analyzed with CANO in each of the reefed stages as well as the full-open configuration. When the load is divided by the rated load of each material, all of the loads can be plotted on one dimensional plot as shown in Figure 3. Also shown in the plot is a line representing the inverse of the desired design factor. Any loads that predicted below this line result in positive margins, the further below, the larger the margin. As can be seen in the plot, all of the horizontal elements carry large positive margins.



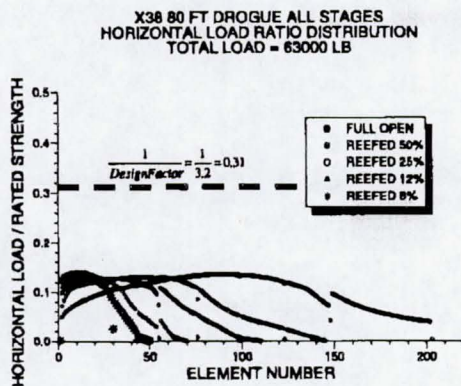


Figure 3  
Loads in Horizontal Elements as a Fraction of  
The Rated Strength of the Material

### Radials & Suspension Lines

The radials were analyzed with CANO as well and the results are plotted in a similar fashion as the horizontals for each of the reefed stages and full-open. The results can be seen in Figure 4 where the inverse of the design factor is plotted for reference. As with the horizontals, the radials can be seen to present large positive margins for the design load.

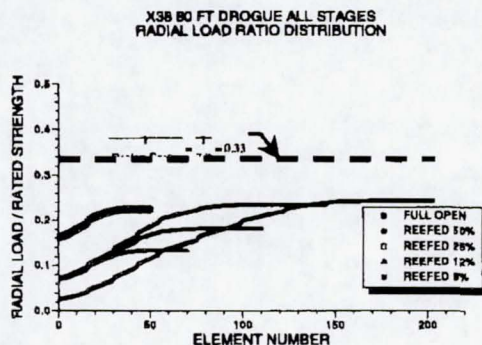


Figure 4  
Loads in Radial Elements as a Fraction of  
The Rated Strength of the Material

### Reefing Lines

Loading in the reefing system can be related to total axial load. The relationship is a function of canopy porosity and reefing ratio. The load in the reefing line has been calculated using the fraction of axial load as shown in the Table 7.

Table 7 Reefing Line Load for Each Reefed Stage	
Reefing Ratio	Ratio of Reefing Line Load to Axial Load
6%	2%
13%	3%
25%	4%
50%	5%

The loading in the reefing ring and the attachment ( $F_{radial}$ ) can be found from the load in the reefing line and the geometry of the to be (for a large number of gores)

$$F_{radial} = \frac{2\pi F_{reefing\ line}}{N_{Gores}} \quad (2)$$

The reefing ring has been found to start deforming at 1000 lbs and the reefing ring attachment has been pulled tested in three different configurations with the weakest orientation yielding a strength of 1030 lbs.

The expected load, material strength and design factors can all be combined to find the safety margins shown in Table 8.

### Riser

The riser legs are constructed out of nominal 20,000 lb Kevlar webbing. Tensile tests have shown a minimum splice strength of 20,320 lbs. With 10 legs, this gives a total riser capacity of 200,320 lbs. With a maximum predicted load of 59 Klbs and a design factor of 3.6, this yields a safety margin of 0.21. If one of the legs of the riser were to fail, the crossover straps would carry the load to the adjacent riser legs and a positive margin would exist at a lower design factor (common practice for a degraded condition).

### Testing

Space restrictions for this paper preclude in-depth discussion of all the testing done to date in this program. Hence, the individual material, joint, and scale model testing will be dispensed with here in favor of a discussion of the full scale system tests



Table 8 Expected Load, Material Strength, Design Factor and Safety Margin for the Reefing System for all Stages of Inflation															
				Expected Load (lbs)						Safety Margin in Each Stage					Minimum Safety Margin
	Stage	Design Factor	Material Strength (lbs)	First	Second	Third	Fourth	Full-Open		First	Second	Third	Fourth	Full-Open	
Item															
Total Load (lbs)			(Includes Splice Efficiency)	56K	33K	44K	54K	59K							
Reefing Line															
	1st	3.6	9884	1120						1.48					1.48
	2nd	3.6	9884		990						1.81				1.81
	3rd	3.6	9884			1760						0.58			0.58
	4th	3.6	9884				2700						0.03		0.03
Reefing Ring		1.4	1000	88	78	138	212			7.10	8.16	4.15	2.36		2.36
Ring Attachment		2.8	1030	88	78	138	212			3.12	3.66	1.62	0.71		0.71

### DTV Tests

The 80-ft.-dia. drogue was initially tested using a cylindrical Drop Test Vehicle provided by Pioneer Aerospace Corporation. The DTV was approximately 24 inches in diameter and 21 ft long. It could be ballasted up to approximately 15 Klbs. In a test, the DTV was loaded with the packed 80-ft.-dia. drogue parachute, a pilot parachute to deploy the test parachute, and a programmer parachute initially affixed to the rear end of the vehicle.

The test apparatus was lifted with a Chinook helicopter to altitudes ranging from 10-14 Kft (see Figure 5). Upon release, the programmer parachute would maintain positive control of the DTV and provide the force necessary to deploy the pilot parachute when the programmer was cut away. The cutting action was timed to achieve the correct dynamic pressure at deployment through the use of a pyrotechnic delay, explosive line cutter.

Upon cutaway, the programmer parachute would deploy the pilot parachute that would in turn deploy the drogue parachute. Considerable altitude is expended in these types of tests just to accelerate the DTV up to the desired dynamic pressure. Insufficient altitude could be

attained to test all four stages of the drogue parachute in any one test. Instead, since the DTV was much lighter than the design payload (15K vs. 25K) at least one reefed stage could always be skipped to reduce the altitude required for the test. Table 9 summarizes the 4 DTV tests and the reefed stages loaded in each test.



Figure 5  
15K Drop Test Vehicle Lifted by a Chinook



### Pallet Tests

Numerous tests have been performed in "Pallet Tests". In these tests, a standard weight tub/pallet combination typically used for aerial delivery training missions is used to test the parachute system as shown in Figure 6. To date, 9 pallet tests have been performed using the new 80-ft.-dia. drogue parachute. In these tests the initial deployment dynamic pressure is greatly reduced from that expected in an actual application since the payloads are extracted and dropped from a standard Air Force cargo aircraft (C-130, C-141, or C-17) at 130-150 KCAS. (Compared to the design maximum for the X-38 vehicle of ~300 KCAS.)



Figure 6  
Typical "Pallet" Test Article

Because the initial dynamic pressure is low, the drogue parachute in these tests is deployed immediately to "3<sup>rd</sup>" stage, once again to conserve altitude. However, for pallet tests that incorporate a 25K payload, the "4<sup>th</sup>" and Full-Open stages experience their design loads. A summary of the pallet drop tests to date can be found in Table 9.

### Vehicle Tests

To date there has been only one vehicle drop test that incorporated the new 80-ft.-dia. drogue (see Figure 7). This was the first flight of the V131R X-38 vehicle. This vehicle is a remanufactured version of the original 80% length scale, V131 vehicle ballasted to the maximum extent possible (18Klbs). All of the free flight vehicles are dropped from the NASA/Dryden Flight Research Center B-52. In this flight, a dynamic pressure of 280 psf was achieved at the time of drogue deployment. This was the first test in which the parachute performance in the wake of the vehicle could be assessed. The peak load produced by the drogue can be found in Table 9.



Figure 7  
Test of Vehicle 131R with 80-ft.-dia. Drogue



Table 9  
Drop Tests

Date	Test Designator	Reefed Stages Utilized	Maximum Measured Load (Klbs)	S/N Parachute Tested	Comments
10/18/1999	P2D29*	1 <sup>st</sup> , 2 <sup>nd</sup> , 3 <sup>rd</sup> , and 4 <sup>th</sup>	59	001	First test of new drogue (S/N 001)
10/28/1999	P2D30	1 <sup>st</sup> , 2 <sup>nd</sup> , 3 <sup>rd</sup> , and 4 <sup>th</sup>	Not Avail.	"	
1/19/2000	P2D28	1 <sup>st</sup> , 2 <sup>nd</sup> , 3 <sup>rd</sup> , and 4 <sup>th</sup>	41	"	First use of new drogue to deploy the parafoil
3/10/2000	DTV7†	2 <sup>nd</sup> , 4 <sup>th</sup>	64	"	First high Q test of drogue
4/13/2000	P2D31	3 <sup>rd</sup> and 4 <sup>th</sup>	46	"	
4/25/2000	DTV8	1 <sup>st</sup> , 2 <sup>nd</sup> , and 4 <sup>th</sup>	47	"	
6/22/2000	P2D32	3 <sup>rd</sup> and 4 <sup>th</sup>	41	"	
9/18/2000	DTV11	1 <sup>st</sup> , 2 <sup>nd</sup> , and 4 <sup>th</sup>	Not Avail.	"	
9/26/2000	P2D33	3 <sup>rd</sup> and 4 <sup>th</sup>	Not Avail.	"	
11/2/2000	P3D6	1 <sup>st</sup> , 2 <sup>nd</sup> , 3 <sup>rd</sup> , and 4 <sup>th</sup>	64	"	
1/23/2001	P2D34	3 <sup>rd</sup> and 4 <sup>th</sup>	33	002	First test of S/N 002
1/29/2001	DTV14	1 <sup>st</sup> , 2 <sup>nd</sup> , and 4 <sup>th</sup>	Not Avail.	"	First test with Zylon Suspension Lines
2/27/2001	P2D36	3 <sup>rd</sup> and 4 <sup>th</sup>	Not Avail.	"	
4/24/2001	P2D37	3 <sup>rd</sup> and 4 <sup>th</sup>	Not Avail.	"	

\* - For the X38 program, "PxDy" denotes test designator "y" in Phase "x". Phase 2 uses platform drops from aerial delivery aircraft (130-150 KCAS). Phase 3 involves solely vehicle type payloads (V131, V132, V131R).

† - DTVz denotes test number "z" utilizing the heavy (up to 15,000 lb) Drop Test Vehicle (DTV) dropped from a Chinook helicopter

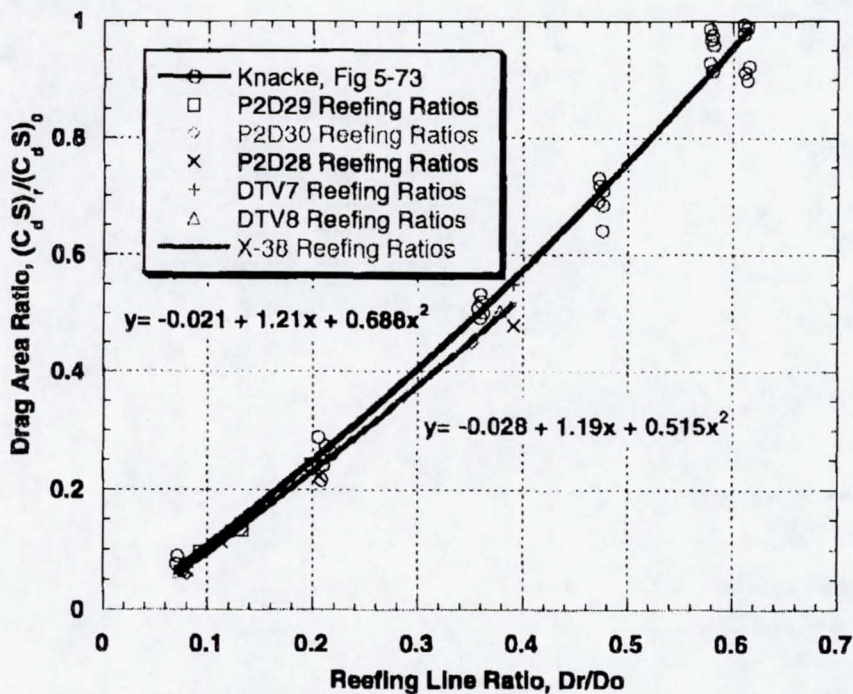


Figure 8  
Relationship between Drag Area Ratio and Reefed Diameters for the 80 ft.  
Ribbon Drogue as Compared to General Ribbon Parachute Data



Data from these tests have allowed the construction of a curve relating the drag area of the reefed parachute to the length of the reefing line as shown in Figure 8. Also shown for comparison is a general curve for ribbon parachutes<sup>5</sup>. The two curves agree well for very low reefing line ratios and differ more as the parachute is allowed to approach full open. While not proven, the authors suspect this is due to two things. The general data is predominantly for conical shaped canopies with 1.0  $D_0$  length suspension lines versus the X38 data that is for 1.2  $D_0$  lines and the quarter-spherical canopy shape. Equations representing the 2<sup>nd</sup> order, least squares fit to each of the data sets are also shown in Figure 8 adjacent to the curves.

### Conclusions

In conclusion, a new, ribbon drogue has been designed and tested for use in the X38 parachute system. The drogue parachute uses a modern canopy shape, materials and construction practices allowing a very large amount of drag area to be produced for the weight of the parachute. The drogue is also very robust and damage tolerant incorporating redundancy and large design factors into the basic design. A test program has allowed the drogue to be proven across the design dynamic pressure range with varying payload weights before it was required to be used on tests involving the very valuable X38 free flight vehicles.

### Acknowledgements

The authors would like to acknowledge the support from NASA-Johnson Space Center Personnel, especially John Muratore, Jenny Stein, and Ricardo Machin. We would also like to thank Pioneer Aerospace Corporation for supplying and preparing test payloads and supporting tests in the field, especially that from Roy Fox, Tom Bennett and John Smith.

### References

1. Wilson, J. R., "CRV Investment Offers Safe Return," pp. 28-32, 38, Aerospace America, June 1997.
2. Wailes, W. K., "Advanced Recovery Systems for Advanced Launch Vehicles (ARS) Phase 1 Study Results," AIAA-89-0881, presented at the 10<sup>th</sup> AIAA Aerodynamic Decelerator Systems Technology Conference, Cocoa Beach, FL, April 18-20, 1989.
3. Wailes, W. K., "The Guided Parafoil Airborne Delivery System Program," AIAA-95-1538-CP,

presented at the 13<sup>th</sup> AIAA Aerodynamic Decelerator Systems Technology Conference, Clearwater Beach, FL, May 15-18, 1995.

4. *V201 Recovery System Requirements Document, X-38 Project, Draft, May 18, 1999*, National Aeronautics and Space Administration, Johnson Space Center, Houston, TX.
5. Knacke, T. W., *Parachute Recovery Systems Design Manual*, NWC TP 6575, Naval Weapons Center, China Lake, CA, 1991.